Review Article

Restorative procedures in disturbed function of the upper airways - nasal breathing

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Abstract

These days, functional rhinosurgery is almost always taken to mean the improvement of nasal airflow. However, air should not only pass through the nose without obstruction. It needs to be warmed, moistened and filtered. This requires sufficient air/mucous membrane contact by spreading airflow over the entire turbinate region, as well as regulation of nasal airway resistance and the degree of turbulence within the nasal cycle. These factors are not considered enough in the concept of functional rhinosurgery.

There cannot be a rigid concept for functional/aesthetic rhinosurgery, the surgical procedure must be adapted to the individual anatomy and pathology. In spite of this, it must be clear (based on evidence) which surgical steps can solve a functional problem of the nose in the long term. This paper cannot explain evidence-based treatment strategies to restore nasal respiratory function because in all branches of rhinosurgery, there are no prospective studies available with a sufficiently high sample size and long-term results objectivized by functional diagnosis.

Studies available on septal surgery show better results for SP after Cottle than for SMR after Killian. However, the success rate of a 70 to 80% improvement in nasal breathing is not satisfactory. The incidence of postoperative, dry nasal mucosa is also too high.

The task of rhinology is to stress the functional side of rhinosurgery more. This includes preoperative analysis of the causes of disturbed respiratory function using the functional diagnosis methods available, the use of evidence-based surgical techniques and postoperative, objectivized quality control. More research needs to be done on the physiology and pathophysiology of nasal airflow as well as on the effect of rhinosurgery on airflow. Numerical flow simulation can contribute greatly to this because the effects of shape changes on the flow can be visualized. Methods need to be developed which can be used for routine, diagnostic recording of warming, moistening and filtering of the respiratory air.

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1. Introduction

Disturbed nasal function is a common reason why a patient consults a rhinologist, the obstruction of nasal breathing being to the fore. However, the nose is the part of the airway that has more tasks than just allowing air to pass through freely. It also has important tasks for breathing: it has to warm, moisten and filter the inhaled air. It has to regulate the degree of turbulence and airflow resistance within the nasal cycle so that the total resistance of the nose is adapted to physical activity and remains a preliminary resistance tool for the lung [1], [2].

Most rhinosurgeons only see the symptom of obstructed nasal breathing as a functional disorder. This is why the literature nearly exclusively contains papers in which nasal obstruction is the indication for functional rhinosurgery. The actual respiratory function of the nose to warm, moisten and filter the inhaled air has been given little notice to date. This is why functional rhinosurgery to date has nearly only the aim of widening the airway canal but not of maintaining and reconstructing the structures important for function.

Rhinological experience has shown that outer nose deformities often result in nasal breathing obstruction. Conversely, we can say that correction of the outer nose is a condition for unobstructed nasal breathing in many cases [3], [4], [5], [6], [7], [8]. This is why we use the logical term of "functional/aesthetic rhinosurgery" these days. The connection is made clearer by the fact that most patients desiring rhinoplasty do not want it just for aesthetic or just for functional reasons [9].

Stoksted [10] pointed out that Killian's SMR was seen too optimistically for a long time because no studies on long-term results were available. Unfortunately, this critical note also applies to the operating methods used today. In most publications, the time of the follow-up investigation is not long enough after the operation, the sample size is very small and the follow-up methods are very different, making comparisons impossible. There is often no objectivization of pre-therapeutic and post-therapeutic findings using functional diagnosis. For example, no study has an evidence level greater than 3 according to the recommendations of the Oxford Centre for Evidence-based Medicine [http://www.cebm.net/levels_of_evidence.asp]. This is why this paper cannot make any evidence-based recommendations on functional/aesthetic rhinosurgery. Neither can it give evidence-based information on the incidence of complications or late sequelae in functional/aesthetic rhinosurgery, which would help as a basis for the sound diagnosis of our patients. Instead, I was forced to collate information on tried and tested methods in functional rhinosurgery so far. However, this should also be viewed critically because some surgical steps which achieve a very good result in the hands of an experienced surgeon may end up as a failure in the hands of a beginner.

In light of this terrible state, I am excused for including personal findings and experience in this paper. After 40 years of devoting my attention to the respiratory function of the nose and rhinosurgery, I perhaps have both the right and the duty to pass on what I have found.

Due to the prescribed length of this paper, not all branches of functional restorative rhinosurgery have been dealt with in the required depth. After weighing up the importance for daily, routine rhinological work, I had to shorten or even leave out some branches completely. I have not explained the connections between the morphology of the nose and its function, something which is essential for rhinosurgery, and refer you to the relevant literature [11], [12], [13], [14], [15].

This paper does not explain rhinosurgical measures like a textbook. I would refer you to the relevant surgical textbooks for information on surgical procedures. Those from Huizing/de Groot [16] and Behrbohm/Tardy [17] should be stressed as they particularly consider the functional aspect of rhinosurgery.

2. Septal and turbinate surgery

2.1 Septum and turbinates from a physiological point of view, rhinosurgical consequences

The division of the nose by the septum into two sides, each side with its own vascular and nervous system, should be seen in connection with the nasal cycle, first described by Kayser [18]. The nasal cycle is an important condition for the respiratory function of the nose [19], [20], [21], [22]. Whereas a slight and predominantly laminar flow passes through the nose in the resting phase, a strong flow in the working phase with a predominantly turbulent character ensures sufficient contact of all flowing particles with the mucous membrane [12], [13], [19]. From this viewpoint, it is useful when the septum divides the nose into two sides which are approximately the same width so that reciprocal swelling and subsidence of swelling on both sides leads to an approximately equal flow and similar turbulence behaviour, both in the working phases and the resting phases. As early as in 1882, Zuckerkandl [23] established in his anatomical studies that the septum is not straight but approx. in the middle between the lateral nasal walls in a skull which is often not symmetrical. He invented the term "physiological septal deviation".

The literature cites an incidence of septal deviation (SD) of up to 58 % in neonates [24], [25], [26], [27] and 16 % to 88 % in children and adults [25], [28], [29], [30], [31], [32], [33], [34], [35], [36]. Roblin, Bewander and Dinis [37], [38], [39] pointed out that a deviation does not inevitably cause complaints. Thus a difference must be made between physiological and pathological SD. Studies conducted by Sipilä [40] and Jessen [41] also speak in favour of this - they reported that patients with SD were free of complaints after conservative treatment.

We define physiological SD as a curvature of the septum without subjective and objective obstruction to nasal breathing. Physiological deviation fulfils the requirement mentioned above in connection with the nasal cycle of a central septum rather than a straight one. This has two consequences for functional rhinosurgery:

• The indication for SP is not a deviated septum in itself, but rather only a deviation which causes elevated airway resistance. This indication can only be made using preoperative functional diagnosis. Several authors regard RMM as a suitable method [40], [42], [43], [44]. This is contradicted by Dinis [38], who didn't find a better success rate in septal surgery when a nasal obstruction was established preoperatively using RMM. The reason for this is that respiratory resistance of the nose is not only caused by an SD [37], [38]. In addition to SD, turbinate hyperplasia, isthmus stenosis, inspiratory alar collapse or pathological turbulence behaviour are often the actual reasons for the elevated resistance. These causes are often overlooked and the deviation is regarded as the sole reason for the complaints. Although RMM measures elevated resistance, it does not give any information on the cause and localization of the resistance. This is why the method is not suitable for solving this problem and must be dismissed under the heading of "useful in isolated cases", as laid down in the German ENT-Society's guidelines. However, RMM has now been refined to RRM. Today, a combination of RRM with ARM and LRM can not only diagnose the extent of a nasal obstruction. It can also diagnose its cause [12]. This makes it possible to rule out physiological deviation as a cause of obstructed nasal breathing and to verify the actual cause of the complaints.

• The aim of SP should not be a straight septum. The septum should be positioned in the middle between the two lateral walls.

Nearly every SD is accompanied by compensatory turbinate atrophy on the convex side and compensatory turbinate hyperplasia on the concave side of the deviation. The turbinates obviously have the ability to fit into the space defined by the shape of the septum in such a way that the space important for the respiratory function of the nose remains intact if possible.

Air flow follows the route of least resistance. Considerable, localized dilations, such as following extensive turbinate resection, lead to a deterioration in the flow distribution in the cavity because the

air only flows through the greatly dilated area. The parts of the cavity in which the space has a normal width are no longer ventilated enough. A further increase in turbulence also occurs because the increase in cross section in the diffusor of the anterior cavity now continues into the middle cavity. Thus extreme dilation in the area of the turbinates should be avoided at all costs. Such a dilation occurs, however, when the septum is straightened too much during SP and when extensive TP is performed on the concave side of the deviation. This results in the atrophic turbinate on the convex side of the SD not being able to compensate enough for the very wide cavity caused by the straight septum. On the concave side of the deviation, there is also a cavity which is too wide due to extreme turbinate reduction, and the turbinate is prevented from performing the required compensatory constriction by reduction of the corpus cavernosum and scarring. This results in increased turbulence with drying out and crusting on both sides as well as the subjective feeling of obstructed nasal breathing.

In summary, deviation of the septum from a straight surface and the size of the turbinates should not be regarded in the preoperative assessment and the operation. What's fundamentally important is the space between the septum and the turbinates. It must be shaped in such a way as to freely allow the alternating swelling and subsidence of swelling of the turbinates in the nasal cycle.

The septum and outer nose form a unit [6]. The septum has a supporting function under the lateral cartilage with which it forms a cartilage union called septolateral cartilage. It is responsible for the projection and protection of the cartilaginous nose. A deformed septum is the most common cause of a nasal obstruction, A pathological change in the septum is seen in nearly all nasal deformities. That is why septal correction is a fundamental component in both functional and aesthetic aspects of RP.

SP is the most common operation in rhinosurgery [39]. Wrongly, no great importance is attached to it. Anyone who has had something to do with rhinosurgery knows how problematic an SD can be and how imaginative and experienced a surgeon has to be to successfully solve all septum problems [45], [46], [47]. The complexity of the deviated septum, the strategy which cannot be predetermined, the many errors and complications in surgical treatment in connection with the unsatisfactory results (see 2.3) should prevent us from traditionally handling SP as a beginner's operation [45], [48] and should motivate us to pay more attention to septal surgery.

2.2 Surgical procedure in septoplasty

There is no rigid course in septal surgery. The surgical procedure depends on septum pathology, which can vary greatly from individual to individual [47]. However, it should basically follow the eight steps proposed by Huizing [16] and expanded on by Pirsig: analysis, approach, mobilization, resection, reduction, reconstruction, fixation and follow-up.

2.2.1 Analysis

In addition to the history and X-rays of the paranasal sinuses, preoperative analysis includes structural and functional diagnosis [41]. At the end of this analysis, the extent of impaired function and which structures have caused it should be clear. Several structures can affect function to differing extents. An obvious septal deviation is often not the only cause [39], [49], and thus sole septoplasty would not sufficiently solve the problem.

2.2.2 Approach

The hemitransfixion incision has proven itself as an approach to the septum. All cartilaginous and bony parts of the septum can be reached from here. Textbooks recommend making the hemitransfixion incision 1 to 2 mm above the caudal septal border. However, orientation at the caudal septal border is difficult as it is often dislocated, too long or too short. Better for orientation is the skin-mucous membrane border. The hemitransfixion incision should be 1 to 2 mm below this border but definitely on the cartilaginous base. It should be guided slightly laterally on the vestibulum floor. This results in less traumatization by stretching when the speculum is inserted. Incision in the mucous membrane should

be avoided if possible because heavy bleeding occurs, the mucous membrane tears easily when inserting the speculum and the transport of mucus by mucociliary activity is impaired postoperatively due to the scar [49].

2.2.3 Mobilization

Complete mobilization of all deformed or dislocated parts of the septum is an important condition for a good, postoperative functional and aesthetic result. Mobilization of the septum starts with exposure of the cartilaginous and bony septum. This is done by preparing the upper and lower tunnel as taught by Cottle [50]. Tunnel creation should be according to septal pathology [49]. Lower tunnels are not required in every case [51]. They should, however, be practised by beginners because they are needed in difficult deformities and thus need to be mastered. In many cases, the experienced surgeon will use what's known as the posterior entry. It should be noted that the arteries and the incisive nerve can be injured when creating the lower tunnel [49], [51], [52].

Only one-sided creation of the upper tunnel as proposed by Cottle must be viewed critically. Despite careful preparation, there is one-sided injury to the cartilage surface and subsequently unforeseeable bending of the quadrangular lamina [49], [53], [54], [55], [56], [57]. This is why many surgeons now prefer bilateral detachment of the mucoperichondrium. Another advantage is the better vision and mobilization. This is required above all in post-traumatic SD where there are often incomplete fracture lines which can be better identified and subsequently disintegrated with bilateral tunnelling [49]. This minimizes the rate of recurrence after septum operations.

Preparation of the tunnel must be strictly subperichondral or subperiosteal. This spares the tissue in the perichondrium or periosteum and reduces the risk of perioperative bleeding and postoperative mucous membrane atrophy as a result of a nutritive disorder of the cartilage. During preparation, the upper and lower tunnels are joined gradually. In post-traumatic deviations, there are often scarred adhesions near former fractures which have to be cut sharply.

In the septum, the formation of what's known as a "swinging door" [58], [59], [60], [61], [62], [63] after lower horizontal and posterior vertical chondrotomy often achieves sufficient mobilization. However, several vertical chondrotomies are often required. These should end upwards approx. 1 cm under the dorsum [16].

Osteotomies are advised to mobilize the bony septum. These must be performed with great care because the perpendicular lamina inserts in the cribriform lamina and this can fracture if too much force is used [64]. This is why osteotomies with a chisel or osteotome are required to achieve a predetermined fracture site in the approximate region of the perpendicular lamina.

2.2.4 Resection

Resection of pathologically deformed parts of the septum is required in marked deformities, particularly as a result of pre-pubertal traumatization. The ridge and spur are resected in any case. The decision whether partial resection or replacement grafting (see 2.2.5) can solve the problem is difficult and requires the surgeon to have a lot of experience [49]. Vertical strip resection in the cartilaginous septum is often needed so that the different parts of the septum can adjust to the median line one after the other without overlapping. Horizontal strip resections are required when the septum is too high. The extent of resection and subsequent reduction and reconstruction depends solely on the pathological changes and findings from the analysis. Excessive and too little resection should be avoided [49].

2.2.5 Reduction and reconstruction

After resection, all the parts of the cartilaginous and bony septum remaining in the nose are reduced in the median line. They must be adjusted without tension. If this is not the case, mobilization must be completed.

The septum should be reconstructed in such a way that it has a three-layer structure in all parts [65], [66], [67], [68], [69]. In the cartilaginous nose, this prevents saddling or columella retraction as a result of scar shrinkage, septal mucosal atrophy, perforation and "septal flapping" [70], [71]. The three-layer structure also makes preparation easier in revision surgery.

During reconstruction, many surgeons used one-sided groove incisions to straighten the curved septal cartilage in order to relieve tension on this side. However, this process cannot be controlled and thus the extent of change in curvature cannot be predicted. Thus there is a risk of recurring deviations. This fact has been described several times in the literature and has also been proven in experiments [57], [72], [73], [74], [75], [76]. This is why it is advised against using this method.

At the end of reduction and reconstruction, the septum should be adjusted without tension in the middle between the two lateral nasal walls. The caudal septum should be placed in a columellar pocket between the two medial alar cartilage shanks. When reconstructing the septum, it should be remembered that the septum has a supporting function in the area of the cartilaginous nose, i.e. it is responsible for the projection and protection of the cartilaginous nose [77]. This is why this area should be reconstructed with a stable, continuous cartilage or bone fragment. It should be 21 to 24 mm high in women and 24 to 27 mm high in men. The parts of the septum lying behind can be filled with small cartilage or bone fragments and with crushed material [16], [74].

Septal reconstruction is often made more difficult by the fact that there is loss of cartilage as a result of trauma, inflammation or a previous operation, or the septal cartilage is not suitable for reconstructing a straight, stable caudal septum due to severe deformity or fracture. In this case, "*replacement grafting*" must be performed or the caudal septum is reconstructed with a transplant. Replacement grafting [74], [78], [79], [80], [81] is based on the experience that the septum parts further back in the nose are often considerably less deformed and traumatized and can thus be used as straight, stable material to reconstruct the caudal septum. Replacement grafting is a suitable method of solving many problems in the "difficult septum" [78], [80], [82]. Temporary guide sutures have proven useful in the caudal region when reimplanting the stable septal plate. These sutures are fixed to the transplant and passed outside through the outer skin on the nasal dorsum and columella [78], [83].

If there is not enough suitable material available from the posterior septum for replacement grafting, another autogenous transplant is required. Masing and Hellmich [57], [84], [85], [86], [87], [88] worked out basic principles in this respect. Many rhinologists have studied the issue of the ideal material [76], [89], [90], [91], [92]. There is agreement that in free transplantation, autogenous cartilage has very low absorption and thus the best long-term results [91], [93], [94]. This is why it is the most common transplant material used in rhinosurgery [95]. For free transplantation, it can be taken from the ear [78], [96] or the rib [76], [78]. In the latter, only the tension-free middle third may be used [55]. This is why the inner third can remain in situ when removing the cartilage. This considerably reduces postoperative pain when breathing and the risk of pneumothorax. There is a risk of a rigid nose when autogenous bone is used from the bony septum [76], [97], the iliac crest [98], the skull cap [99], [100] or the turbinate [101]. This is why cartilage should be preferred when reconstructing the mobile, outer nose.

Allogenic or xenogenic cartilage or bone transplants preserved in cialite or thimerosal should no longer be used [see rhinoplasty guidelines at http://www.hno.org. Alloplastic materials in various forms (sponge, mesh, solid) are offered and tested by industry again and again [102], [103], [104], [105], although Peer found out as far back as in 1955 [106] that they are "constantly implanted by one group of surgeons and just as constantly have to be removed by another group of surgeons after various periods".

2.2.6 Fixation

Fixation of all mobilized, reduced and reconstructed septal parts is an important factor for a good functional and aesthetic result. At the same time as fixation, adaptation of the mucoperichondrium on both sides to the cartilaginous and bony septum, prevention of bleeding and formation of an intraseptal

haematomy and prevention of adhesions with the lateral nasal wall are required [107], [108], [109]. Sutures, various nasal packs and splints are available for this.

Fixation of the cartilaginous septum is always with sutures. Good fixation of the reduced septum using a suture on the anterior nasal spine is particularly required when the connection between the cartilaginous septum and the premaxilla has been cut [110]. It is advantageous in some cases to chisel or ream a groove in the premaxilla in which the septum is adjusted subsequently. This stops the septum from slipping to the side. Dorsal dislocation of the septum with saddle formation in the cartilaginous region must also be avoided by fixing the septum to the spine [49], [81], [111]. Further fixation of the cartilaginous septum can be achieved by mattress sutures or a suture on the lateral cartilage in the roof area [56], [112]. Additional use of fibrin glue is advised in some cases [113].

Many surgeons use a nasal pack as an internal dressing. According to Guyuron [114], nasal packing has a good effect on the postoperative result in relation to improvement of nasal breathing, there was less recurrence of deviation and there were less adhesions. Nasal packing positions the mucoperichondrium or periosteum on the cartilage or bone and accelerates epithelial wound healing by preventing drying out [115].

The type and duration of nasal packing depends on the surgeon, there is no standard [107], [108], [109], [116]. There is also no study which has determined the optimum time nasal packing should be left in place; recommendations range between 2 hours and 8 days [114], [117], [118], [119], [120]. A longer time in situ is recommended to prevent postoperative bleeding and haematomas [121], [122], particularly as patients have got used to oral breathing after 48 hours and the complaints caused by nasal packing diminish [109], [123]. A longer time in situ does not lead to more common inflammation [124]. From a physiological wound healing point of view, nasal packing should be left in place for 4 to 5 days because only very slight autogenous firmness exists in the first 3 days due to formation of soluble collagen, fibronectin and hyaluronic acid. Firmness is only definite on the fourth day by the formation and deposition of type I collagen fibres [109], [125]. Nasal packing for a longer period of time should also be recommended from the viewpoint of fixation of the septum in the middle between the lateral nasal walls, because the mobilized septum is positioned in the middle between the two lateral nasal walls due to the bilateral postoperative swelling of the turbinates. On the basis of his clinical experience, Huizing [16] also recommends nasal packing for fixation for 3 to 5 days.

Many are now opposed to the use of nasal packing. The reasons given for this are mainly the pain and frequent bleeding when removing the packing, but also the patient discomfort [108], [115], [117], [118], [120], [124], [126], [127], [128], [129], [130], [131]. Complications with a fatal outcome [132], [133], [134], [135], [136], [137], [138] have worried many surgeons. Since the introduction of the "Diagnosis Related Groups", nasal packing is also seen as disadvantageous from an economic point of view because inpatient treatment is recommended [115] when using nasal packing due to the risk of posterior dislocation [136], [137].

Toxic shock syndrome after nasal surgery occurs in very rare cases (incidence of 0.0016%), both with and without nasal packing [132], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148].

Pneumatic balloon packs must be rejected due to the possibility of mucous membrane necrosis occurring due to the perfusion pressure of the mucous membrane being exceeded as a result of the packing pressure [115].

If you decide to use nasal packing, you must ensure that the disadvantages are minimized. In this connection, loose insertion [114] of narrow packs is to be recommended. It must be remembered that the mucous membranes are still shrunk at the end of the operation and that postoperative swelling could cause increased pressure and thus malaise or pain if the nasal pack is too tight. After osteotomy with additional RP, excessive pressure from the inside can break apart the bony pyramid [108].

Use of nasal packs with a fine-pored surface or impregnation with ointment of the gauze reduces granulation and thus pain when removing the nasal pack to a minimum [114]. Pain when removing the

nasal pack is less with a longer insertion time. The risk of paraffinomas when using ointment can be reduced considerably when all incisions are closed carefully with sutures [149]. As postoperative dislocation of nasal packs is potentially life-threatening [137], [150], nasal packs must be reinforced. Weber has compiled an information sheet which can be downloaded from the Internet http://www.rainer.weber.de.

Nasal packs can be dangerous for patients with obstructive sleep apnoea syndrome because they can cause the condition to deteriorate or it can appear for the first time [151], [152], [153]. Thus if there are predisposing factors [152] or in known sleep apnoea syndrome, depending on the severity, postoperative monitoring with pulse oximetry or even intensive care, temporary CPAP mask ventilation via a mouthpiece and earliest possible removal of the nasal packs are to be recommended.

Due to the disadvantages listed of using nasal packing, may surgeons prefer splints (with and without breathing tubes). However, a study carried out by Guyuron [118] showed that the subjective discomfort with splints was not less. Breathing tubes usually get blocked after a short period of time [132], [154]. The following points must be noted when using splints:

• The splints must not touch the roof or floor of the nose.

• If transseptal mattress sutures to fix the splint are too loose, they don't fix the septum enough. If they are too tight, perfusion disorders may occur as a result of postoperative swelling of the septal corpus cavernosum. This increases the risk of infection and perforation.

• The splints often cause the septum to be too straight and not sufficiently medial.

It must also be said for splints that no information can be given on material and in situ time based on a prospective study. Splints can be painful. The daily aspiration required and removal of the splint is an unpleasant and sometimes painful process for the patient. Perforations occur more often [120], [155].

In summary, it can be said that both nasal packs and splints have advantages and disadvantages and it's up to the surgeon to decide which advantages are important to him and which disadvantages he's prepared to accept. Wound occlusion with mattress sutures [114], [155], [156], [157] looks very inviting at first glance but appears to be problematic for the bony septum. A final solution does not appear to be in sight, even with self-disintegrating nasal packs.

2.2.7 Follow-up

Follow-up is an important basis for the surgeon's experience. That's why the functional result should not only be checked subjectively, it should also be checked using functional diagnosis. This is the only way to differentiate between suitable and unsuitable operating strategies and conduct postoperative quality assurance, which should be called for in rhinosurgery.

2.3 Long-term results in septoplasty

The typical complications after Killian's SMR should be clearly reduced by the three-layer structure of the septum using the Cottle technique. Table 1 (Tab. 1) shows studies on results and complications following SMR. As a comparison, Table 2 (Tab. 2) shows results and complications after SP. The different studies cannot be compared because they have different designs. They do not provide much evidence because the sample size is too small, the follow-up was too soon after the operation or the postoperative result was not objectivized using functional diagnosis. In general, it can still be said that considerably fewer deformities of the outer nose and septal perforations were found after septoplasty. The number of dry noses with crusting is strikingly high, even after SP (up to 33%). Although the results regarding improvement of nasal obstruction appear to be better in SP than in SMR, there is still a large number of patients (20 - 30% on average) in whom sufficient improvement was not achieved.

2.4 Surgical procedure in turbinate hyperplasia

After septum deviation, enlarged turbinates are the second most common cause of obstructed nasal

breathing [158]. It is usual to talk of hyperplastic turbinates, although it is not always genuine hyperplasia. There is often dysregulation as a result of an allergy, caused by physical or chemical noxae, as side effects of medicines, in psychoses and systemic diseases, in connection with hormonal disorders and in acute and chronic inflammation, or there is turbinate hypertrophy on the concave side of a septal deviation [158]. The latter turbinate hypertrophy is not a pathological phenomenon, but rather a physiological adaptation of the turbinate to the space prescribed by the septum, with the aim of creating a narrow space. It is recommended that compensatory turbinate hypertrophy should be reduced during septal surgery [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170].

On looking through the literature, one gets the impression from the variety of procedures used for turbinate reduction [171], [172] that every new surgical procedure invented by biomedical engineering is tried out on the turbinates. This is the case because procedures to date have not achieved the desired long-term success. Thirteen different techniques for turbinate reduction are recommended [173]. Lenders reviewed and critically assessed the procedures [174], [175]. The number of procedures is an indication that none of them is able to produce satisfactory long-term results in pathological turbinate hyperplasia [158]. The reason for this is not the operating technique but the dysregulation which continues to exist. However, a false technique can permanently damage the respiratory function of the nose. Apart from compensatory turbinate hyperplasia, surgical turbinate reduction is only indicated when conservative treatment has not achieved sufficient success [173].

It must be said that there are also no prospective studies on surgery of enlarged turbinates in which the long-term results of various procedures can be compared in a randomized manner and in a sufficient sample size. In 11 patients with SD, Hilberg [164] found that the patients on whom TP had been performed in connection with SP were more satisfied 3 months postoperatively. The study conducted by Grymer [163] on 80 patients also showed better results 3 months after the operation when anterior TP was performed at the same time as SP in marked deviation. TP did not produce better results with less marked deviation. Passali [176] compared electrocoagulation, cryocoagulation and laser coagulation with submucous resection with and without lateroposition and turbinectomy. Unfortunately, anterior TP was not included in this study. The sample size for the different groups is also small. Vidian neurectomy, cryosurgery and injection of corticosteroids or sclerosing substances are no longer performed [173].

The aim of turbinate surgery must be to reduce the size of the turbinates to create a sufficient space whose width can be regulated in the nasal cycle. For this, the corpus cavernosum of the turbinate must not be damaged too much and the mucous membrane surface should be reduced as little as possible [173], [177]. These requirements may be met more easily by a sparing surgical resection [173], [177], [178], [179], [180] because the effect of turbinate reduction and surface damage during coagulation remain difficult to regulate, even with modern procedures.

SD which occurred after puberty often does not require any accompanying surgical measures on the turbinates because increased swelling is only a compensatory mechanism. In these cases, a normal-sized and normal-shaped turbinate is seen after swelling has subsided. Turbinate resection would cause a postoperative space which would be too large. We have observed that the turbinate "learns" very quickly postoperatively to fit into the new, now slightly narrower space. The condition for this of course is that a space which is too narrow has not been created due to a straight septum.

Surgical techniques used for reduction of turbinate size may be divided into three groups: lateroposition, resection and coagulation. These shall be discussed briefly in the following.

Lateroposition [178] of the lower turbinate by fracturing the turbinate bone at its insertion at the lateral nasal wall is an effective method [131] and is advised in compensatory turbinate hypertrophy in connection with SP [173]. We believe that it is the method of choice in this case, particularly in SD occurring before puberty in which the turbinate bone has grown far medially for compensatory reasons. Thus the turbinates can sufficiently fill the very wide space created by the deviation.

Lateroposition is a simple but effective method with a very low complication rate [181]. Sometimes an incision on the head of the lower turbinate and creation of a predetermined fracture site with the chisel on the insertion of the bone are required because the bone is often very thick and stable here and cannot be fractured [171].

Total turbinectomy of the lower turbinate [161], [165], [167] can considerably reduce nasal airway resistance. This is why the literature cites success rates of over 80 %. Still, this method cannot be recommended. In addition to the risk of secondary bleeding and postoperative sicca symptoms, the negative effect on respiratory function should be seen as the crucial disadvantage of this surgical procedure. As air flows only through the wide space now created after resection, the middle and upper turbinates are no longer ventilated and are thus not available for warming, moistening and filtering the respiratory air [11], [14]. The negative effects of extensive resection (dryness with crusting, fetid nasal secretions and bleeding) have been described in the literature many times [181], [182], [183], [184], [185].

Partial turbinectomy [186], [187] was developed due to the negative experience with total turbinectomy. Many surgeons have limited themselves to the anterior part of the turbinate because their experience has shown that this part often causes nasal obstruction [170], [186], [188]. This method is also too destructive because the head of the lower turbinate is resected. This permanently damages the regulatory mechanism for turbulence within the nasal cycle [19].

Many surgeons use *submucosal turbinate resection* [189], [190] which only resects the anterior parts of the turbinate bone and/or the soft tissue. Several rhinosurgeons combine lateroposition with simultaneous submucosal resection of soft tissues [191]. According to Rohrich [190] and Egeli [171], submucosal resection is the best method of turbinate reduction with the best long-term results and the least complications [190].

Another way to reduce turbinate size is *turbinoplasty*, described by Freer [192] as early as in 1911 and recommended 70 years later by Mabry [177], [193], [194]. Parts of the turbinate bone and the lateral mucous membrane sheet are resected and the resulting defect is covered by lateral rotation of the preserved medial mucous membrane sheet. Lenders [174], [175], Galetti [178], Grymer [163], [195], King [196], Illum [172], Marx [197] and Huizing [198] limited surgery to the head of the lower turbinate (what's known as *anterior turbinoplasty*), and achieved good results. Anterior TP is regarded currently as the method of choice [158].

The shaver has also been used for the last 10 years to reduce turbinate size [199]. This is a new instrument, not a new operation. It can be used to reduce turbinate size involving the surface or with submucosal work [200], [201]. The advantages are more rapid work, usually under endoscopic control, ability to be dosed well and few complications. The method is described as effective [202]. A prospective study with long-term results and a large sample size is not yet available.

For *electrocautery*, monopolar parallel electrodes have been available for 100 years and bipolar ones for the last 70 years. The effect is based on coagulation of the corpus cavernosum with subsequent submucosal fibrosis [203]. The use of high-frequency bipolar diathermy reduces damage to the surrounding tissue [204]. Monopolar needle coagulation is very popular because the operating technique is simple [173]. An exact dose is not possible in electrocoagulation [205], which has resulted in necrosis or even complete turbinate loss being described [203], [206]. The desired effect of a reduction in turbinate size is also not permanent [207], [208]. Persistent bleeding and crusting are complications which occur [208], [209], [210].

Argon plasma surface coagulation is an alternative to the procedure of submucosal coagulation. Long-term results are not yet available. *Radiofrequency therapy* to reduce the volume of submucosal tissue without damaging the mucous membrane has also been available for several years. According to the literature, this procedure is a good alternative but only studies with a small sample size and no long-term results after more than one year are available to date [211], [212], [213], [214].

Size reduction of the turbinates using a laser is becoming more and more popular. Many different types of laser are available. The first argon laser was used in 1977 [215], [216], [217]. Then the use of CO_2 lasers spread quickly [218], [219], [220], [221], [222], [223], [224], [225], [226], [227]. The potassium-titanyl-phosphate laser [228], the Nd:YAG laser [229], the diode laser [230] and the holmium: YAG laser [231] have also been used in turbinate reduction. Most surgeons favour the CO_2 laser because it is available in many hospitals, it is easy to use and can be regulated well. DeRowe's comparison of different laser systems [232] did not show any significant difference between the various systems. The laser systems can be pulsed or non-pulsed. Thus linear and punctiform incisions can be made. The main advantages of laser surgery are its applicability under local anaesthesia for outpatients, a lower tendency to bleed than the surgical procedures and no absolute necessity for nasal packing. The disadvantages as compared to the surgical procedures are the missing regeneration of epithelium [221], [233], [234] and the delayed wound healing. Mucociliary transport time is prolonged significantly after laser surgery [235]. There is also the difficulty of dosage. If you want to keep surface damage low, you only have small volume reduction. If you accept greater epithelial damage, this results in a reduction in function. This is why this method does not suit the functional concept of modern functional rhinosurgery [173].

The success rates for laser surgery fluctuate between 47 % and 89 %. The reason for this large range is the inhomogeneity of the studies. This is why this paper will not go into any more detail on existing studies. A clear, comprehensive review can be found in Tasman [158].

3. Surgery of the bony and cartilaginous nasal pyramid

3.1 Procedure in principle for the correction of the bony and cartilaginous pyramid

Completely different pathologies can be the reason for obstructed function of the nose and disturbed aesthetics. This is why the operating technique in corrective rhinosurgery is not standardized. Rather, the basic techniques of septorhinoplasty are adapted or modified to the specific problem [4], [236]. Having said that, a certain order of surgical steps similar to that in SP has proven useful: analysis, approach, mobilization and resection of the septum, mobilization of the bony (and cartilaginous if necessary) pyramid by osteotomy with (if necessary) hump removal, reduction of the bony (and cartilaginous) pyramid, continuation of SP with reduction, reconstruction and fixation, (if necessary) correction with fixation of the lateral and alar cartilage, fixation of the pyramid and follow-up. Correction of the pathological septal configuration is the focus of the operating steps and is the basis for a good, aesthetic and functional result [237].

3.1.1 Analysis

The aim of analysis is to recognize the individual anatomy of the nose and its pathology. It includes

• Rhinological history (subjective assessment of nasal breathing and sense of smell, previous trauma and surgery, allergies, paranasal sinus conditions),

• Inspection and palpation of the outer nose with evaluation of the skin and supporting frame (angles, familial and ethnic characteristics) and standardized photodocumentation.

• Internal inspection, initially without an instrument, with evaluation of the entry area to the isthmus, examination using the nasal speculum and the endoscope before and after the swelling subsides.

• Rhinological functional diagnosis before and after the swelling subsides.

• Analysis of the patient's complaints and his requests and expectations in relation to the result of the operation.

• A summary of all information received up until then, operative planning and a concluding discussion with the patient, indicating the limits to fulfilling his wishes.

When the results of functional diagnosis are available, a second inspection, particularly of the inside of the nose, is often required to find out about which structures in this individual case are responsible for

impaired respiratory function. With defective analysis, particularly insufficient functional diagnosis, it often happens that the actual cause of the complaints is not identified preoperatively and thus the operation is not successful despite skilled correction of several structures [238]. Our experience has shown that isthmus stenosis and inspiratory alar collapse are overlooked most often. Conversely, it also happens that physiological inspiratory aspiration is seen as the cause of the complaints and thus incorrectly operated on. Revision operations in which the diffusor was widened at the wrong site are particularly difficult, causing increased turbulence to continue or even an increase in the patient's complaints.

3.1.2 Approach

A suitable approach is chosen based on the results of the analysis. The first point to be decided upon is whether a closed approach is possible or if an open approach is necessary [239], [240], [241]. In the last few decades, the number of open rhinoplasty operations has increased greatly [241], [242], [243], [244], [245]. La Rosa [240] and Huizing [16] describe the advantages and disadvantages of both approaches. The surgeon's preference should not be the reason for the choice of approach, but rather the individual pathology, the aim of surgery and the experience of the surgeon. Due to the disadvantages of the external approach (external scar albeit aesthetically not problematic and greater traumatization), an endonasal approach should be preferred if possible. This can be used to correct crooked, hump, saddle and tension noses. External rhinoplasty gives a direct view of the cartilaginous and bony nasal pyramid. Correction of deformities of lateral and alar cartilage and of caudal septal cartilage as well as the insertion of transplants can be handled more precisely and the result can be fixed more securely. The open technique is being recommended increasingly in problems in the area of the alar cartilage, inspiratory pathological aspiration of the ala, congenital deformities and revision rhinoplasty [78], [239], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254], [255], [256], [257], [258], [259], [260], [261], [262], [263], [264], [265], [266], [267], [268], [269], [270], [271], [272], [273].

The columellar incision required in open rhinoplasty can be W-shaped [274], V-shaped [275] or serial [276], [239], [241], [247], [277], [278]. The columella scar is not an aesthetic problem [245] if exact adaptation in the suture is ensured [279].

Several incisions are available in closed rhinoplasty. The hemitransfixion incision has proven useful to access the premaxilla and septum (see 2.2.2). The intercartilaginous incision which is usually bilateral is suitable for décollement and work on the bony and cartilaginous roof of the nose. An approach via the vestibular margin [280] or a transcutaneous one [281] is possible for lateral osteotomy. The approach via the external oral cavity which is used less often has the following advantages:

• Less traumatization of the nasal vestibulum

• An osteotomy line deep at the base of the pyramid

• Greater freedom of movement with the chisel or osteome, thus enabling transverse osteotomy to be connected to lateral osteotomy in one move

• Postoperative drainage option for the haematoma which often occurs in lateral osteotomy.

• The approach from the external oral cavity enables widening of the nasal base at the same time, e.g. in the tension nose. Connective tissue attachment of the ala to the lateral piriform crest is detached with the chisel or osteotome. Subsequent nasal packing in the nasal vestibulum helps the insertion of the alar to be positioned several millimetres laterally, thus enabling an end result where the nasal basis can be widened on both sides by 1 to 2 mm. This contributes to a good functional result without external scarring.

There are various options for transverse osteotomy:

• Using the same approach as for lateral osteotomy (a curved osteotome is often used then because the osteotomy direction changes)

• Transcutaneous via a stab incision in the outer skin on the nasion, laterally on the intercanthal line or

on the head of the eyebrows

• Transpalpebral [282].

The choice of approach for lateral and transversal osteotomy is also not based on evidence, it depends on the surgeon's preference. Transcutaneous osteotomy leaves scars. They are small and hardly noticeable but they remain visible in many cases. Transcutaneous approaches should be avoided because the osteotomy can be performed exactly using other approaches.

In the case of the approach to the lateral alar cartilage shanks using the closed technique, in addition to the intercartilaginous incision there are also the infracartilaginous and transcartilaginous incisions which are the basis of the dislocation and eversion method (see 4.2.2).

3.1.3 Septal surgery with mobilization and resection

Septal correction has a central role in functional/aesthetic rhinosurgery. In a crooked nose, the axial deviation of the septum must be corrected as well, in the saddle nose the septum is not high enough and in tension noses the septum is too high. Thus septal correction is the basis of functional/aesthetic rhinosurgery and should be performed at the start of the operation. The initial steps are those described in 2.2.3 and 2.2.4.

3.1.4 Mobilization of the bony and cartilaginous pyramid

Before mobilization of the nasal pyramid, décollement from an intercartilaginous incision is performed in the subcutaneous layer. Its purpose is to push excess skin aside after hump removal and height reduction (tension nose), and to prevent the nasal pyramid from returning to its old position in a crooked nose. The extent of décollement depends on the pathology. It should, however, never reach the lateral osteotomy so that a connection between the skin and mobilized bony pyramid remains. The motto here is as little as possible and as much as necessary.

Medial to lateral osteotomy is performed to mobilize the bony pyramid. It is required in crooked noses and when removing material from the dorsum to close the open roof. One side of the bony pyramid is often longer in crooked noses which occurred before puberty. Wedge osteotomy with wedge excision must be performed on this side (see 3.2.1).

All surgeons perform paramedial and transverse osteotomies transperiostally. In lateral osteotomy, many surgeons opt for an external and internal subperiosteal tunnel in the region of the osteotomy. The intact periosteum above the cut bone is a good basis for healing and prevents dislocation of the mobilized bone [283]. On the other hand, it must be said that surgeons have also had good experience with transperiosteal lateral osteotomy. It's quicker and, apart from cutting the periosteum, is less traumatizing because less soft tissue has to be detached from the bony pyramid. Smooth cutting of the periosteum with a sharp instrument does not appear to cause any disadvantages. Tardy [284] recommends the use of very narrow osteotomes (2 or 3 mm) to unite both advantages in the hope that large parts of the periosteum remain uninjured during osteotomy. Ford [283] also recommends leaving periosteal bridges to prevent postoperative dislocation of the bony pyramid. Finally, it must be said, however, that personal experience and views play a role here and that there is no clarifying prospective study to date [16]. Internal and external periosteal tunnels are required in wedge osteotomies which are recommended for correcting crooked and tension noses.

Detachment of the lateral cartilage from the septal cartilage is usually required to reduce the cartilaginous pyramid. The connection between the bony pyramid and the lateral cartilage must not be detached because this connection cannot be reconstructed and cannot be replaced by anything.

3.1.5 Reduction of the bony and cartilaginous pyramid

Reduction and alignment in the midfacial line of the face is possible following complete mobilization of the septum and the bony and/or cartilaginous pyramid. Different techniques are used to reduce the bony pyramid: the one or two-sided outfracture (lateroposition of the osteotomized part), infracture

(medial position of the osteotomized part), push-down (pushing down the osteotomized bony pyramid in the piriform aperture) or let-down after wedge resection (pushing down the laterally shortened, bony pyramid with occlusion of the dehiscence caused by wedge resection). There is also the rotation technique for crooked noses caused by postpubertal trauma in which the bony pyramid is the same height on both sides but dislocated.

From an aesthetic point of view, it is important that the nose is straight but also that it fits into the face which is often asymmetrical. From a functional point of view, it must be remembered when reducing the bony pyramid that the lateral cartilage pushes itself under the bony pyramid and is fixed to it. Thus reducing the bony pyramid always causes a change in the cartilaginous pyramid. From a functional point of view, this changes the configuration in the area of the nasal valve and the lateral wall of the diffusor. This can have both a negative functional effect, such as narrowing of the nose in the infracture technique, and a positive effect such as the reduction in height in tension noses and the outfracture technique.

3.1.6 Continuation of septal surgery with reduction, reconstruction and fixation

Reduction, reconstruction and fixation of the septum is performed according to the aspects mentioned in 2.2.5 and 2.2.6.

3.1.7 Correction and fixation of the alar cartilages

Correction of both the position and/or the shape of the alar cartilages is often required from an aesthetic and functional point of view. If there is a very large nasiolabial angle, the alar cartilage is rotated too far on the lateral cartilage, resulting in airflow which is too low in the functional space. However, it is more often the case that the alar cartilages are rotated downwards and cause a small nasolabial angle. In these hanging noses, the airflow is too high in the turbinate region. The alar cartilages have to be rotated again on the lateral cartilage and fixed to the lateral cartilage in this position.

A false shape (inside convex) and a loss of elasticity in the lateral shank of the alar cartilages may cause inspiratory aspiration, even at a low rate of airflow, and thus cause increased respiratory resistance. In these cases, correction of the alar cartilage shanks is required (see 4).

3.1.8 Pyramid fixation

The pyramid should be fixed with an internal and external dressing. The internal dressing is the nasal pack (see 2.2.6). The external dressing consists of an adhesive plaster and a solid dish, the material of which is left up to the surgeon (plaster, plastic, aluminium). In this case too, there are no studies which give definite information on how long the external splint has to be worn. Most surgeons let their patients wear this splint for two or three weeks, followed by a further two or three weeks only at night. A preoperative test with the plaster to be used is recommended due to the risk of a complication caused by a plaster allergy.

Unsatisfactory aesthetic and functional results occur with incomplete mobilization, false reduction or subsequent, insufficient fixation of the nasal pyramid. The most common complication is the open roof [285], [286], [287], [288], [289]. A nose which is too wide [246], [259], [285], [287], [290], [291] or too narrow [289], [290], [291], [292], [293] and a saddling [287], [290], [294], [295], [296] (which particularly occurs with unsatisfactory reconstruction and fixation of the cartilaginous septum) may also result. Aesthetically unpleasant stepping on the lateral bony pyramid at the height of the lateral osteotomy has also been described in the literature several times [246], [259], [285], [290].

3.1.9 Follow-up

The points mentioned in 2.2.7 apply for follow-up in rhinoplasty.

3.2 Particular cases in the correction of the deformed nasal pyramid

3.2.1 Crooked nose

In crooked noses, the aesthetic problem is always linked to a functional problem [285], [297], [298], [299], [300], [301], [302], [303]. It must be analyzed whether the crooked nose occurred before or after puberty and whether it affects the area of the bony, cartilaginous or both parts of the nose. As the septum is deviated in every crooked nose [187], [297], [304], septoplasty makes up an essential part of the surgery [298]. Replacement grafting is required in many cases [80].

A crooked nose which occurred before puberty has grown crooked. Thus the pyramid has two sides of differing length which need to be shaped symmetrically. On the bony pyramid, this can be done by oblique hump removal if there is a hump. However, *wedge resection* at the base of the pyramid in connection with lateral osteotomy is better. This was described by Joseph as early as in 1907 [305] and by Fomon [306]. For incomprehensible reasons, it was hardly performed at all for decades and was first brought back into the concept of modern functional/aesthetic rhinosurgery by Huizing [307]. In a prepubertal crooked nose, it allows symmetry to be restored exactly. The long-term results of wedge osteotomy are excellent [308]. It is important that the wedges are extracted completely, even when they break into several fragments as is usually the case.

The recurrence rate is high in crooked nose correction [309]. This can only be prevented by complete mobilization of the septum and pyramid, exact restoration of symmetry and good fixation [310]. Other reasons for an unsatisfactory long-term result are postoperative scar contraction and what's known as the "memory effect". This exists above all in prepubertal crooked noses which then grew crooked. The soft tissues (skin and musculature) of the nasal pyramid are then also asymmetrical. The memory effect can be reduced by extensive décollement [311] and detachment of the nasal muscle laterally on the pyramid, the nasal depressor muscle on the columella base and the nasal dilator muscle on the lateral alar cartilage shank [81]. Partial resections of the lateral and alar cartilages are required sometimes [309], [312], [313], [314], [315], [316], [317], [318], [319].

3.2.2 Tension nose

The outer and inner nostrils are slit-shaped in a tension nose due to the septum being too high. This increases airflow resistance and the alae are often subjected to inspiratory aspiration. The entrance in the nasal diffusor is narrow, which is why the airflow resistance increases additionally as a result of heavy turbulence.

Relaxing of the cartilaginous nose can only be achieved by reducing septal height in the roof or basally. We can see the functional effect in the increasing roundness of the inner and outer nostril. The increasing concavity of the lateral vestibular wall simultaneously reduces inspiratory aspiration.

The push-down technique was used previously to lower the bony nasal pyramid. It didn't give satisfactory functional results, particularly when it was combined with an infracture [320], because this narrowed rather than widened the isthmus. The let-down technique with bilateral wedge osteotomy and septal shortening produces better functional and aesthetic results.

3.2.3 Saddle nose

In saddle noses, functional diagnosis in the analysis has to clarify whether there is a functional disorder. There is often increased turbulence with crusting as a result of the ballooning phenomenon, and airflow resistance can be elevated. The basis of the functional disorder in the cartilaginous saddle nose is a septum which is too low. This doesn't give the lateral cartilage enough projection. Consequently the caudal end of the lateral cartilage is dislocated downwards and posterior and thus the isthmus is deformed completely. The nasal valve angle is often not much greater than 20°. In the cartilaginous/bony saddle nose, the entire lateral cartilage is dislocated because it is fixed to the bony pyramid. In many cases the alar cartilage and thus the level of the outer nostrils are rotated upwards. The functional consequence of this is deficient airflow in the area of the upper cavity.

As the pathology of the saddle nose can vary a lot, the operative concept must be based on the

patient's individual pathology [321]. A saddle nose can be corrected using the closed technique but the open approach should be favoured. In minimum saddling without a functional disorder, the saddling can be rectified by an implant on the dorsum. This is malpractice in the case of a functional disorder because the implant on the nasal dorsum puts additional pressure on the dislocated lateral cartilage and thus intensifies the functional problem. In cartilaginous saddle nose with functional impairment, septal reconstruction with sufficient height is always required [310], [322], [323], [324], [325], [326]. If there is no suitable material in the nose for replacement grafting, autogenous ear [78], [96] or rib cartilage [76], [78], [81] can be used. The isthmus wall is often shrunk by scars and must be lengthened by a V-Y plasty before the lateral cartilages can be reduced to their normal position.

In a bony saddle nose, lateral osteotomy must be deep to align the bony pyramid as effectively as possible and to narrow the often wide pyramid [327]. The ballooning phenomenon is solved by reconstructing the normal height and narrowing the pyramid.

The angle or L-span used previously [328], [329], [330] is no longer recommended due to the very rigid nose.

4. Surgery on isthmus stenosis and inspiratory alar collapse

4.1 Preliminary physiological and pathophysiological remarks

A few thoughts should first be shared on the terms isthmus, nasal valve and valve region from a physiological and pathological viewpoint. The upper part of the isthmus was described by Mink [331] as the nasal valve. The crack-shaped transverse area of the nasal valve is limited medially by the septum and laterally by the caudal end of the lateral cartilage. The angle between these two structures should be 10° to 20° [2]. The term valve region is used to take into account the functional importance of this region with the head of the lower turbinate. However, this is not logical from a functional and flow dynamics point of view. Although the lower turbinate begins directly behind the isthmus, from a flow dynamics point of view the head of the lower turbinate is at a level with the septal corpus cavernosum in the anterior cavity. The functional importance of the isthmus is different to that of the anterior cavity. This is why it appears to be logical to talk about a "nasal isthmus", equivalent to the functional internal orifice, and a "nasal diffusor", equivalent to the anterior cavity with the head of the lower turbinate and the septal corpus cavernosum.

The nasal isthmus is the narrowest point and has the greatest amount of resistance in the entire airway [2], [332], [333], [334] with functional importance [335], [336], [337]. Although the isthmus plays the crucial role for airway respiratory resistance and along with septal deviation and turbinate hyperplasia, is one of the main causes of nasal obstruction [338], [339], [340], it is often overlooked as a cause of nasal obstruction [2], [332], [341]. In many cases, the reason for this is a concomitant SD which is not, however, relevant from a flow dynamics point of view [332], [339]. This physiological SD is then regarded as the cause of the obstruction and further causes are not searched for.

From a rhinosurgical point of view, it is important that dilation of a small cross section (e.g. the isthmus) has a much better effect on reducing resistance than dilation of a large cross section [38], [342]. Small constrictions in the isthmus cause greater complaints, whereas deviations and marked crests or spurs in regions IV and V after Cottle hardly affect the airflow resistance.

In addition to the problem of the narrowest part of the nose, the lateral wall is mobile and as a result of the Bernoulli effect can be aspirated. This causes a further reduction in area with an increase in resistance [343], [344]. The entire lateral vestibular wall is mobile. This is why it is better to talk about alar collapse and not nasal valve collapse [343], [344]. The elasticity of the lateral and alar cartilage and the inserting muscles counteract collapse. Elasticity is increased by returning of the caudal border of the lateral cartilage (in the sense of a U splint) and by the connection of the cephalic part of the alar cartilage with the lateral cartilage lying below [344], [345], [346], [347]. Interruption of this connection can be the basis of pathological alar collapse [291], [339]. Aspiration of the lateral vestibular wall at

higher rates of airflow (above 500 ml/sec) is a physiological phenomenon and is intended to protect the nose from flow which is too powerful [335], [336], [337]. However, an inspiratory aspiration phenomenon is often found at a clearly lower airflow rate. Operative treatment is recommended in these cases.

Unfortunately, isthmus stenosis and pathological alar collapse are the consequence of previous rhinoplasty in many cases [348]. As prevention is the best treatment, rhinosurgeons should know and avoid all risks when operating.

4.2 Surgical procedure

4.2.1 Analysis

Aspiration of a mobile elastic wall depends on the flow rate, the elasticity and the shape of the wall. According to Bernoulli's law, the greater the flow rate, the greater the negative pressure and thus the aspiration of the mobile wall. Loss of elasticity and the shape of the wall (a wall curved outwards reduces the aspiration phenomenon and a wall curved inwards favours it) also have an effect on inspiratory alar collapse. This is why clinical examination and functional diagnosis before the operation must clarify which of these causes, or which combination of these causes, are present in the individual case and need to be surgically eliminated. Often it's not the nasal valve but the lateral vestibular wall with its cartilage, connective tissue and skin [81], [349], [350]. The following should be looked out for during the inspection

• Size and shape of the isthmus

• A septum deviation in Region II or other narrowing in the isthmus

• Caudal lateral cartilage border which is too tight (nasal valve angle below 15°)

• Deformed caudal lateral ligament or lateral shank of the alar cartilage

• Reduced elasticity of the lateral and/or alar cartilage

• A wide columella

• Scar stenosis in the valve or on the isthmus floor

• Narrow, bony piriform aperture.

Kern [351] reviewed all possible pathological changes to the nasal valve. Deviations in Cottle Region II are very common. In this region, it must be observed in particular that medianization of the septum brings about an improvement in resistance on the narrowed side but at the same time also a deterioration in resistance on the side which was wide up until then. This is why functional diagnosis prior to the operation must be used to check whether resistance on the opposite side is so low that medianization of the septum will not lead to postoperative complaints on the other side. If the resistance is not low enough, the entire isthmus region (see 4.2.3) must be dilated in connection with septum reduction.

When analyzing inspiratory alar collapse, it must be clarified whether it is a physiological or pathological aspiration phenomenon. RRM can be used to determine the flow rate at which aspiration of the ala begins. It is also possible to objectivize the extent of the increase in resistance by aspiration. Correspondingly, we also get information on the extent of improvement in resistance due to the planned operative measure. In nearly all cases, it is seen that alar collapse is not the only cause of an increase in resistance. Thus sole stabilization of the mobile lateral wall would not sufficiently improve the patient's complaints. This is another reason why preoperative functional diagnosis is so important.

When performing the Cottle test, the result must be regarded critically because on the one hand, dilation of this most narrow point can lead to an improvement in nasal breathing even in a normally configured isthmus region, and on the other hand, not all stenoses can be dilated by lateral traction.

The nasal vestibule should be inspected both without an instrument and with speculum and endoscope to determine which parts of the lateral nasal wall are aspirated. The following structures are possible candidates:

• The caudal border of the lateral cartilage (nasal valve)

• The area of the lateral shank of the alar cartilage

• The lateral inferior skin part of the ala below the lateral shank of the alar cartilage.

The reason for alar collapse also has to be determined. This can be a loss of elasticity but also an increased Bernoulli effect due to elevated flow rates at a constriction.

In some cases, analysis may show that mechanical aids which can keep the nasal vestibule open are better than an operation. This is not as comfortable for the patient but better, particularly when the problem cannot be solved by surgery [352], e.g. in the classical case of "revision no. 10".

4.2.2 Approach and mobilization

Again, the approach depends on the individual pathology. Possible incisions are the hemitransfixion incision, the intercartilaginous, transcartilaginous and infracartilaginous incisons. After these incisions are made, the caudal lateral cartilage border and the alar cartilage can be exposed with the dislocation or eversion method. In the case of severe changes in the area of the alar cartilage, but particularly when a cartilage transplant is required for stabilization, the open approach is recommended for precise localization and fixation.

This is followed by mobilization of dislocated or deformed parts of the septal, arytenoid and alar cartilage.

4.2.3 Resection, reduction, reconstruction

These steps depend on the individual pathology and include dilation of narrow passages and improvement in elasticity by strengthening, supporting or strongly bending the cartilage outwards. The options for *dilating an isthmus stenosis* are

• Septoplasty in deviations in Region II (see 2.2)

• Rectifying a tension nose (see 3.2.2) by let-down and outfracture

• Valve surgery by resection of the caudal border of alar cartilage

• Valve surgery with spreader grafts [259], [260], [286], [291], [292], [338], [353]

• Removal of the lateral piriform crest [354] in narrow piriform aperture

• Osteotomy and outfracture of the bony and cartilaginous pyramid

• Z-plasty in scars [355], [356], [357] or excision of scar tissue [358] with/without full-thickness skin grafts or complete skin and cartilage grafts [348], [359], [360] as well as local transposition flaps [360], [361]

• Narrowing of the columella [362], when the outer nostril is constricted due to a wide columella, by shortening excessively long, medial shanks of alar cartilage, shortening an excessively long caudal septum, resection of connective tissue between the medial shanks of alar cartilage, cutting of the ends of the medial shank of the alar cartilage projecting laterally and medianization using mattress sutures [363].

For stabilization in loss of elasticity

• The connection between the lateral and alar cartilage can be strengthened by rotating the lateral shank of alar cartilage on the lateral cartilage [349], [364] or below the lateral cartilage [365], [366].

• Missing or too weak parts of the lateral shank of alar cartilage can be replaced or strengthened by Batten grafts [291], [367]; these can be additionally supported laterally on the piriform crest.

• Reduced elasticity of the lateral cartilage can be improved by splay grafts [292] or spreader-splay grafts [368].

• A deformed (curved inwards) lateral shank of alar cartilage can be rotated 180° to give it a normal shape (curved outwards) [349], [369], [370].

• A suture between the lateral shank of alar cartilage and the periosteum of the infraorbital margin [371], [372], [373], [374], [375] or the lateral piriform aperture [81] can stabilize the lateral vestibular wall.

• In less marked pathology in the area of the alar cartilage, suturing techniques with/without incisions in the nasal vault are also possible in several cases [376].

Both septal and ear cartilage can be used as transplant material.

5. Functional/aesthetic rhinosurgery in children

Since Ombredanne [377] described growth disorders of the nose after SMR in the middle of the last century, the rule was that functional/aesthetic rhinosurgery was not performed on patients under 16 to 18 years. Since the introduction of plastic reconstructive surgery after Cottle and the fundamental work by Pirsig, Verwoerd, Takahashi and Huizing [75], [378], [379], [380], [381], [382], [383], [384], [385], [386], [387], [388], [389], [390], [391], [392], the indication for, and the time of, functional/aesthetic rhinosurgery has changed in children, Thus oral breathing at rest is now an indication for surgery, even in the first ten years of life [379]. If there is only oral breathing on exertion, the time of the operation should be weighed up carefully [379]. However, the later the operation is performed, the greater the effects of a traumatically dislocated septum on nasal growth and the middle part of the face as well as the consequences of oral breathing. This is why acute trauma should be treated immediately at every age [379]. SP is also indicated in childhood when a growth disorder of the nose and middle part of the face is to be expected due to SD.

The optimum time for surgery on a child's nose cannot be laid down, it must be found out on an individual basis. On the one hand, the earlier, the greater the risk of surgery for growth. On the other hand, the later, the greater the negative effect of the deviated septum on growth and oral breathing on the overall development of the child. The decision is often difficult and it is advised to wait and have yearly check ups (with photodocumentation).

Septal mobilization and reduction is possible without any great risks. Incisions, when required, should be sparing. The connective tissue attachment of the septum to the spine and premaxilla should definitely be preserved and posterior chondrotomy should be avoided. Missing septal parts, e.g. in septal abscesses, must be replaced by autogenous material (ear cartilage). Crests and spurs on the bony septum can be removed.

Asymmetry of the cartilaginous pyramid should be corrected together with the septum to enable further symmetrical growth. On no account should the lateral cartilage be separated from the septal cartilage. The bony pyramid can be corrected. As bone fractures heal completely, osteotomy is not a problem for the growing nose.

The operating principle on children is the more conservative the better. This is why the surgical result is not completely satisfactory in the long term in many cases and necessitates a second operation after puberty.

6. Conclusions

When looking through the literature on functional and functional/aesthetic rhinosurgery in the last 50 years, you predominantly find papers in which the authors describe a new or modified surgical method. They report on their own results retrospectively and often present their own unproven opinions. Expression of one's own opinion in a field where personal experience plays a considerable

role is an important step on the way to finding the method with the greatest benefit for the patient. In spite of this, we should attempt to prove the effectiveness of a method. From this point of view, prospective comparative studies are required at evidence level 1 or 2 in accordance with the recommendations of the Oxford Centre for Evidence-based Medicine. The preoperative and postoperative status must be determined in a case control study by analyzing symptoms, functional tests and perioperative and postoperative complications. The suitable time for follow-up has also not been clarified to date. We can conclude from several studies on long-term results [38], [393], [394], [395] that a follow-up period of 1 to 2 years is useful.

Multicentre studies would be desirable due to the large sample size required. A condition of this of course is that the operating methods in all participating hospitals are comparable and are not varied according to personal preferences of the surgeon.

These studies would also be desirable from the point of view of a useful preoperative discussion with our patients. Up until now, no evidence-based statements could be made on risks and the incidence of complications [52].

We can conclude from studies on long-term results after SP to date that the result of the operation in respect of improvement of nasal breathing and sicca symptoms in the nose is not satisfactory. In addition to the recurrence of deviation, there are various reasons for this:

• False preoperative analysis, the nasal obstruction was not (or not alone) caused by SD, other causes were involved.

• Complete straightening of the septum with concomitant extensive reduction in size of the compensatory hyperplastic turbinate resulted in the cavity being dilated too much.

• The regulatory mechanism for the extent of turbulence was damaged as a result of excessive dilation of the anterior nasal cavity or operative measures on the lower turbinate.

During preoperative assessment and the operation itself, the deviation of the septum from a straight surface and turbinate size are not the only factors which should be considered. The space between the septum and turbinates is of the utmost importance. It should not be dilated as much as possible, rather it must be shaped in such a way as to freely allow on both sides swelling and subsidence of swelling of the turbinates in the nasal cycle. A new motto for septal and turbinate surgery could be: **"Not the septum, not the turbinates - the space between is what's important!"**

Functional diagnosis should be a part of preoperative analysis and postoperative quality assurance for diagnosis and objectivization. This should be laid down in our society's guidelines. More than the flow measured by rhinomanometry and the width of the nose measured by acoustic manometry need to be considered to evaluate the functional status of the nose. These two values are not a measure of an improvement in function and can even increase in a deterioration in function. Currently, the combination of RRM, ARM and LRM is available to objectivize the extent of an obstruction and to differentiate its causes. An important task for us in the future will be to develop methods which could be used in routine clinical diagnosis to measure the warming, moistening and filtering of inspired air. Numerical flow simulation in the nose must also be developed further [396], because it is a suitable method of researching the pathophysiology of nasal airflow and the effects of surgical measures on the respiratory function of the nose.

Research should also deal more with the nasal cycle. Its functional importance has been pointed out again and again ever since its discovery a hundred years ago. Restoration of nasal breathing function also means restoration of the disturbed nasal cycle. However, the control and disorders of the nasal cycle have not been sufficiently researched to date. Obstruction of the nasal cycle caused by SD or pathologically changed turbinates, as well as the effects of SP or surgical measures on turbinates need to be researched in large prospective studies. A start to finding a suitable measuring technique for routine recording of the nasal cycle has been made with LRM.

The patient with functional and aesthetic problems due to a nasal deformity would like a good

therapeutic long-term effect, both functionally and aesthetically. He turns to a plastic surgeon, a maxillofacial surgeon or an ENT specialist. To secure and consolidate a place for rhinology in the field of rhinosurgery in the future, we have to stress our competence in the functional side of rhinosurgery more. The basis for this is to check our knowledge in this area according to the criteria of evidence-based medicine. Intensive research in the area of physiology and pathophysiology and the development of methods of functional diagnosis are required to improve the effectiveness of functional rhinosurgery. The rhinologist's task is to incorporate these results into the concept of functional rhinosurgery and justify them to specialists from other fields. We as rhinologists must also be in a position to solve aesthetic problems to the complete satisfaction of our patients.

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Glossary

ARM - Acoustic rhinometry

LRM - Long-term flow rhinometry

RMM - Rhinomanometry

RRM - Rhinoresistometry

RP - Rhinoplasty

SMR - Submucosal septal resection

SD - Septal deviation

SP - Septoplasty

TP - Turbinoplasty

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Author	Reference	Year	Study Design	Follow-up min.-max. in years	Sample size	Investigative method	Result %			
							Nasal breathing improved	Septal perforation	Outer nose deformity	Dry nose, crusts
Sloth, M	[397]	1976	Retrospective	0.3 – 3	118	subj. assessment	65			
						rhinoscopy		17	1	20
Tuschen, E	[398]	1977	Retrospective	1.5 – 2.5	51	subj. assessment	71			
					41	rhinoscopy	42	14	6	
Bewander, F	[37]	1978	Retrospective	1 - 19	250	subj. assessment	67			
						rhinoscopy		9	7	45
Meinel, J	[399]	1978	Retrospective	0.5 - 2	104	subj. assessment	61			
						rhinoscopy		3	?	22
Peacock, MR	[48]	1981	Retrospective	6 - 8	613	subj. assessment	53			
					53	rhinoscopy	44	4	21	
Haraldsson, PO	[46]	1987	Retrospective	5 - 9	137	subj. assessment	66			
					98	rhinoscopy		8	20	23
Fjerdemal, O	[400]	1988	Retrospective	0.5 - 6	100	subj. assessment	60			
					43	rhinoscopy		12	7	10

Table 1: Studies on long-term results of SMR after Killian

Author	Reference	Year	Study Design	Follow-up min.-max. in years	Sample size	Investigative method	Result %			
							Nasal breathing improved	Septal perforation	Outer nose deformity	Dry nose, crusts
Stoksted, P	[10]	1969	Retrospective	0.5 – 1.5	100	subj. assessment	86			
						rhinoscopy		5	4	23
Shermann, AH	[394]	1977	Retrospective	> 1	49	subj. assessment	82			
Tuschen, E	[398]	1977	Retrospective	1 – 1.8	45	subj. assessment	82			
						rhinoscopy	35	2		4
Dommerby, H	[401]	1985	Retrospective	2 – 5.5	161	subj. assessment	57			
						rhinoscopy	78	2	2	28
Grymer, LF	[341]	1987	Retrospective	1 - 7	42	subj. assessment	76			26
Haraldsson, PO	[46]	1987	Retrospective	5 - 9	86	subj. assessment	77			
					61	rhinoscopy		2	9	33
Fjermedal, O	[400]	1988	Retrospective	0.5 - 6	278	subj. assessment	66			
					69	rhinoscopy		3	7	10
Gordon, ASD	[402]	1989	Retrospective	0.05 - 3	60	subj. assessment	78			
Jessen, M	[393]	1989	Retrospective	0.5 - 1 1 - 11	35	subj. assessment	51 26			
Samad, L	[131]	1992	Retrospective	0.5 - 3	105	subj. assessment	70,5			
Bohlin, L	[45]	1994	Retrospective	0.25 9.5 - 11	63	rhinoscopy RMM	95 84	4	3	
Illum, P	[172]	1997	Prospective	5	50	subj. assessment	76			
					37	rhinoscopy		2		25
Truilhe, Y	[403]	2000	Prospective	0.05	102	subj. assessment	84			
Dinis, PB	[38]	2002	Retrospective	2 - 10	79	subj. assessment	77			

Table 2: Studies on long-term results of SP after Cottle